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DPC-SWICHING TABLE control for PWM Rectifier With the function of an Active Power Filter Based on a Novel Virtual Flux Observer

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Abstract – For improving the quality of the energy transfer from the power supply to the load, and reducing the harmful effects of the harmonics generated by nonlinear load. We propose a new multi-function converter (MFC) as an efficient solution to improve the power quality. This paper presents a new DPC strategy based on virtual flux Observer and switching table to control PWM rectifier achieving by this unit power factor and reducing the harmonic current of the non linear load. The good dynamic and static performance under the proposed control strategy is verified by simulation and experiment.

Index Terms — Harmonics, Three phase APF, IP controller, pulse width modulated, PWM rectifier, DPC, virtual line flux linkage observer.

1. INTRODUCTION

Nowadays, harmonic pollution in electrical power systems due to nonlinear loads such as AC-to-DC power converters has become a serious problem.

To eliminate or reduce harmonics in the power systems, a number of methods have been developed and put into practice. Active power filters and PWM rectifiers are two typical examples of these methods. The active power filter and PWM rectifier have basically the same circuit configuration and can operate based on the same control principle.

Therefore, we can design a power converter capable of both the active filter operation and PWM rectifier operation at the same time. Rectifier to supply DC power to its own load and, at the same time, operates as an active filter to supply to the AC line a compensating current equal to the harmonic current produced by the nonlinear load connected to the same AC line.

This paper presents a new control method entitled direct power control (DPC) strategy based on a virtual flux observer and switching table to control PWM rectifier with the function of an active filter.

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2. CONTROL OF PWM RECTIFIER WITH ACTIVE FILTERING FUNCTION

2.1. Control Method of PWM Rectifier (Virtual Flux)

The aim of Virtual Flux (VF) approach is to improve the VOC [2]. Here it will be used for instantaneous power estimation. The simplified representation of a three phase PWM rectifier system is given by Fig .2, where the phases of line are represented by the virtual induction motor.

Thus, R_f and L_f represent respectively the stator resistance and the stator leakage inductance of the virtual motor. U_{ab}, U_{bc}, U_{ca} are phase to phase line voltages induced by a virtual air gap flux. In another words the integration of the phase to phase Voltage leads to a virtual line flux vector in stationary $\alpha\beta$ coordintes (fig .3)

With these definitions :

$$\varphi_f = \int U_f dt \quad (1)$$

Where

$$\begin{bmatrix} U_{f\alpha} \\ U_{f\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} U_{ab} \\ U_{bc} \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} \varphi_{f\alpha} \\ \varphi_{f\beta} \end{bmatrix} = \begin{bmatrix} \int U_{f\alpha} dt \\ \int U_{f\beta} dt \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} i_{f\alpha} \\ i_{f\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ \frac{\sqrt{3}}{2} & \sqrt{3} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \end{bmatrix} \quad (4)$$

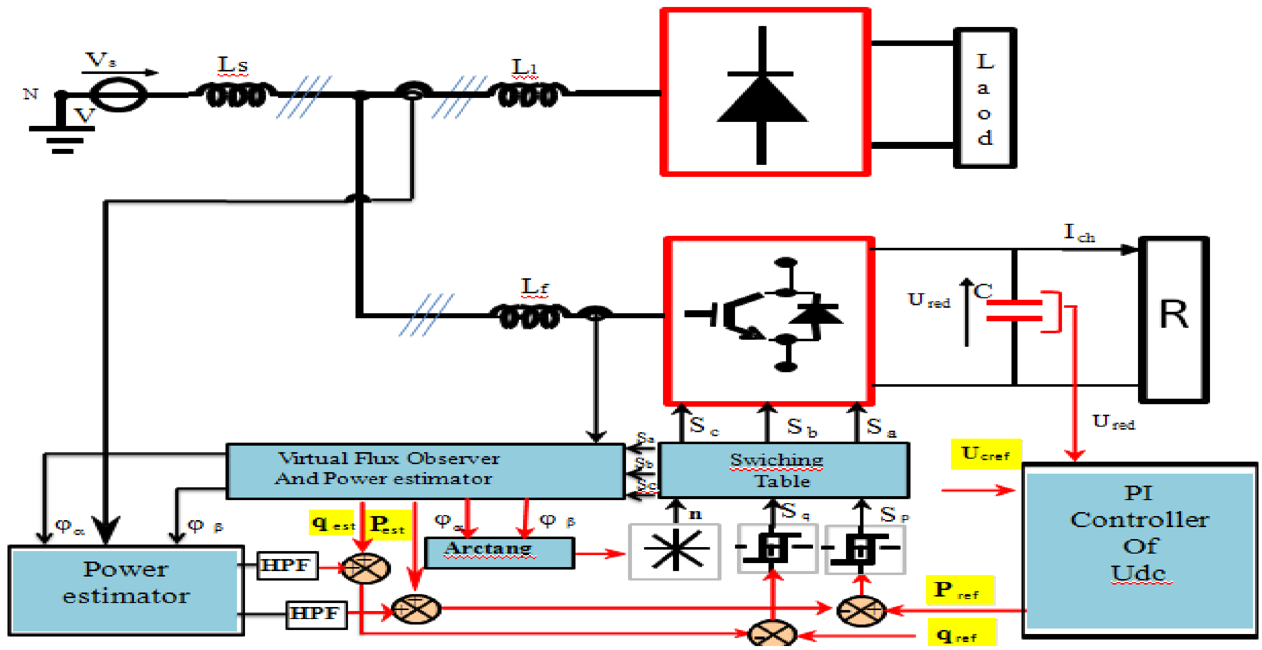

Fig. 1: Control of PWM Rectifier With Active Filtering Function

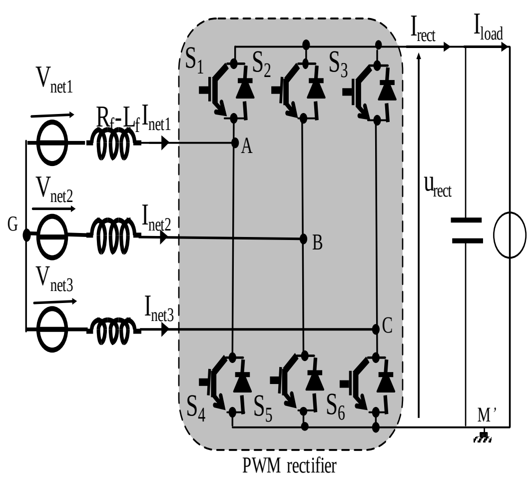

Fig .2. Simplified representation of a three phase PWM rectifier system

$$\begin{bmatrix} U_{s\alpha} \\ U_{s\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} U_{AM} \\ U_{BM} \\ U_{CM} \end{bmatrix} \quad (5)$$

Virtual line flux vector u_s line voltage vector, u_f inductance voltage Vector i_f -line current vector

The voltage equation can be written as

$$U_s = R.i_f + \frac{d}{dt}(L.i_f + \varphi_f) \quad (6)$$

Usually R can be neglected which gives

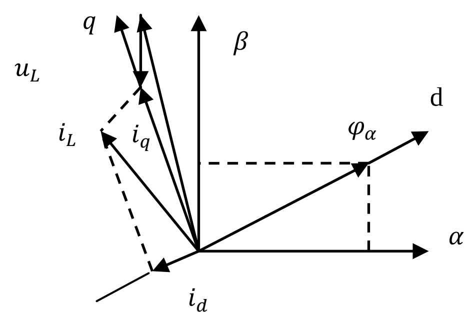

Fig.3. Reference coordinates and vectors φ_L

$$U_s = \frac{d}{dt}(L.i_f + \varphi_f) \quad (7)$$

With the complex notation, the instantaneous power can be obtained as follows

$$\begin{cases} P = \mathrm{Re}(U_f . i_f^*) \\ q = \mathrm{Im}(U_f . i_f^*) \end{cases} \quad (8)$$

Where * denotes the conjugate line current vector can be calculated by the virtual flux

$$U_f = \frac{d}{dt}\vec{\varphi}_f = \frac{d}{dt}(\varphi_f . e^{j\omega}) = \frac{d\varphi_f}{dt} e^{j\omega} + j\omega\varphi_f e^{j\omega} = \frac{d\varphi_f}{dt} e^{j\omega} + j\omega\varphi_f$$

(9)

Where $\vec{\varphi}_f$ denotes the space vector and φ_f its amplitude. For the virtual flux oriented d-q in $\alpha\beta$ coordinates (Fig.3.)

Using (8) and (9)

$$\begin{cases} U_f = \left.\frac{d\varphi_f}{\mathrm{dt}}\right|_\alpha + j\left.\frac{d\varphi_f}{\mathrm{dt}}\right|_\beta + j\omega\left(\varphi_{f\alpha} + j\varphi_{f\beta}\right) \\ U_f.i_f^* = \left[\left.\frac{d\varphi_f}{\mathrm{dt}}\right|_\alpha i_{f\beta} + j\left.\frac{d\varphi_f}{\mathrm{dt}}\right|_\beta i_{f\alpha} + j\omega\left(\varphi_{f\alpha} + j\varphi_{f\beta}\right)\right]\left(i_{f\alpha} - ji_{f\beta}\right) \end{cases} \quad (12)$$

That gives:

$$\begin{cases} P = \left.\frac{d\varphi_f}{\mathrm{dt}}\right|_\alpha i_{f\alpha} + j\left.\frac{d\varphi_f}{\mathrm{dt}}\right|_\beta i_{f\beta} + j\omega\left(\varphi_{f\alpha}.i_{f\beta} + j\varphi_{f\beta}.i_{f\alpha}\right) \\ q = \left.\frac{d\varphi_f}{\mathrm{dt}}\right|_\alpha i_{f\beta} + j\left.\frac{d\varphi_f}{\mathrm{dt}}\right|_\beta i_{f\alpha} + j\omega\left(\varphi_{f\alpha}.i_{f\alpha} + j\varphi_{f\beta}.i_{f\beta}\right) \end{cases} \quad (14)$$

For sinusoidal and balanced line voltage the derivatives of the flux are null. The instantaneous active and reactive powers can be computed as:

$$\begin{cases} \mathrm{P_C} = \omega\left(\varphi_{\mathrm{f\alpha}}.i_{\mathrm{f\beta}} - \varphi_{\mathrm{f\beta}}.i_{\mathrm{f\alpha}}\right) \\ \mathrm{q_C} = \omega\left(\varphi_{\mathrm{f\alpha}}.i_{\mathrm{f\alpha}} - \varphi_{\mathrm{f\beta}}.i_{\mathrm{f\beta}}\right) \end{cases} \quad (15)$$

2.2. Block Scheme of power Virtual Flux observer:

The Basic block scheme of the VF-DPC system is given by Fig.1. The converter voltages are estimated in the block as follows:

$$\begin{cases} V_{f\alpha} = \sqrt{\frac{2}{3}}.U_{dc}\left(S_a - \frac{1}{2}\left(S_b + S_c\right)\right) \\ V_{f\beta} = \sqrt{\frac{2}{3}}.U_{dc}\left(S_b - S_c\right) \end{cases} \quad (16)$$

Where U_{dc} is DC link voltage and $S_a S_b S_c$ switch states of converter. After that the virtual flux components are calculated from the (7)

$$\begin{cases} \varphi_{f\alpha} = \int u_{f\alpha}.\mathrm{dt} + \mathrm{L.i}_{f\alpha}\ * \\ \varphi_{f\beta} = \int u_{f\beta}.\mathrm{dt} + \mathrm{L.i}_{f\beta} \end{cases} \quad (23)$$

According to equation (22) and (23),the integrator can be used to estimate the virtual flux ,but the initial value of flux must be estimated firstly this makes simulation complex and DC offset could be produced easily [9].

The novel virtual line flux observer and the comparison of the observers are showed in fig 4 and fig 5 respectively, which distinctly shows that the novel algorithm responds faster than the traditional control.

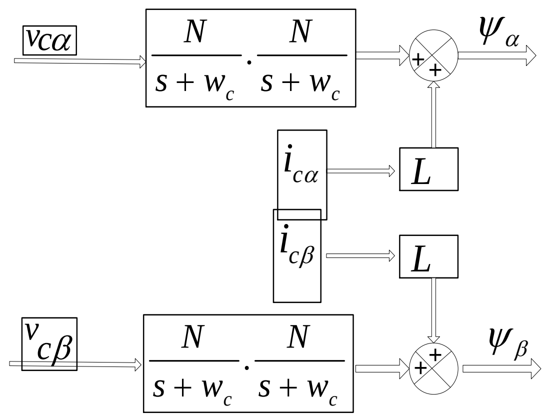

Fig 4 The novel virtual line flux linkage observer

The instantaneous active and reactive powers are observed in the block (power observer) by measurement of line current and the observation of the virtual flux components $\varphi_{f\alpha}, \varphi_{f\beta}$.

The command reactive power $q_{ref}\, q_{ref}$ and active power p_{ref} (delivered form the outer PI-DC voltage controller) values are compared with the estimated (q) and p values, in reactive and active powers hysteresis controllers, respectively.

If (qref -q >H_q) , d_q=1; Else , d_q =0;
If (pref -p > H_p), d_p=1;Else d_p =0; (7)

Hp and Hq are the hysteresis band. Table I shows the switching table for VF-DPC control

Sp	Sq	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8	θ_9	Θ_{10}	θ_{11}	θ_{12}
1	0	V_6	V_7	V_1	V_0	V_2	V_7	V_3	V_0	V_4	V_7	V_5	V_0
	1	V_7		V_0		V_7		V_0		V_7		V_0	
0	0	V_6	V_1		V_2		V_3		V_4		V_5		V_6
	1	V_1	V_2		V_3		V_4		V_5		V_6		V_1

Table 1: SWITCHING TABLE

With:**V_0(000),V_7(111),V_1(100),V_2(110),V_3(010),V_4(011)V_5(001), V_6(101).**

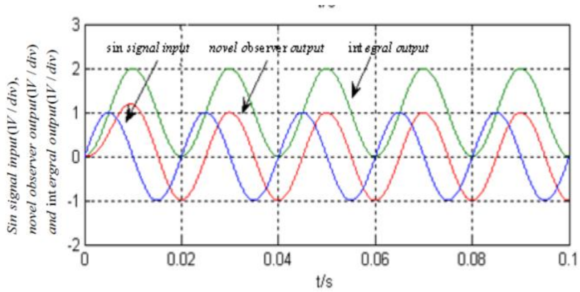

Fig 5 The comparison of the three observer.

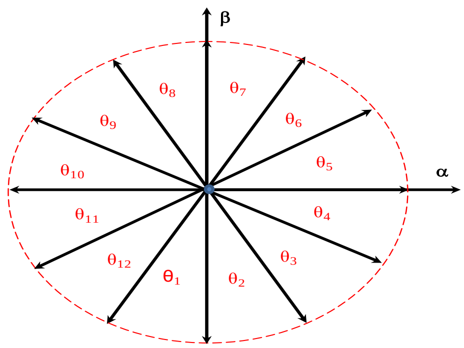

Fig.3.Virtual flux plane 12 sectors

The figure 3 shows the 12 voltage sectors plane for switching table.

3. EXPERIMENTAL RESULTS

In this section, experimental results are shown to test the proposed controller using a prototype. For this purpose, the three-phase two-level power converter of Fig. 6 has been developed, with a digital implementation of the control algorithm that has been executed in a TMS320lf2407-40 MHz which has two high-resolution analog to digital (A/D) converters (0.8μs-10bit) provide very fast processing for fixed point calculations.

TABLE II

ELECTRICAL AND CONTROL PARAMETERS FOR THE EXPERIMENTAL SYSTEM

resistance of reactors	2.9 Ω
inductance of reactors	11 mH
resistance of reactors	2.5 Ω
inductance of reactors	7.5 mH
resistance of line	
inductance of line	
dc-link capacitor	4.7mF
phase voltage (RMS)	110 V
Dc-link voltage	300 V
PWM rectifier load:	110 Ω
diode rectifier load:	42 Ω
The hysteresis band was fixed	0.01

The electrical parameters of which are shown in Table II.

Fig.6. PWM Rectifier With the function of an Active Power Filter experimental test bench.

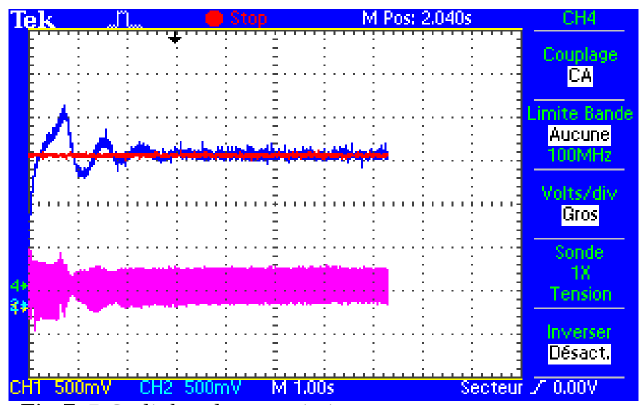

Fig 7. DC –link voltage variation

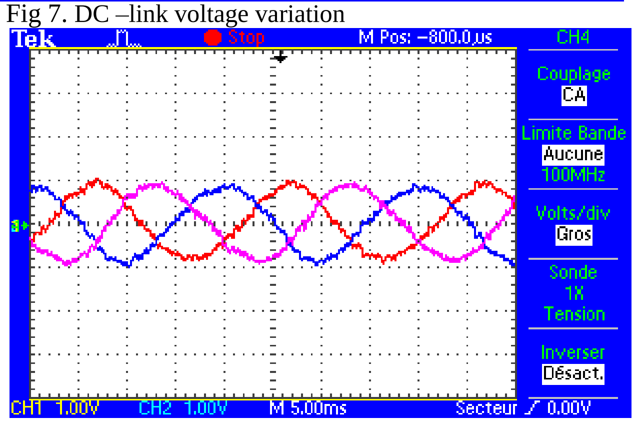

Fig 8. Operation of PWM Rectifier under grid current sag

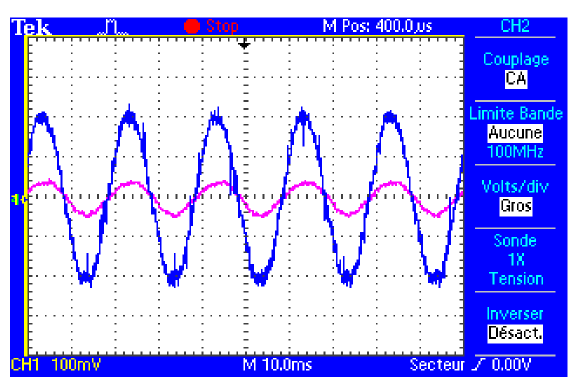

Fig 9. PWM rectifier operation without filtering operation [line voltage (v) and line current (i)].

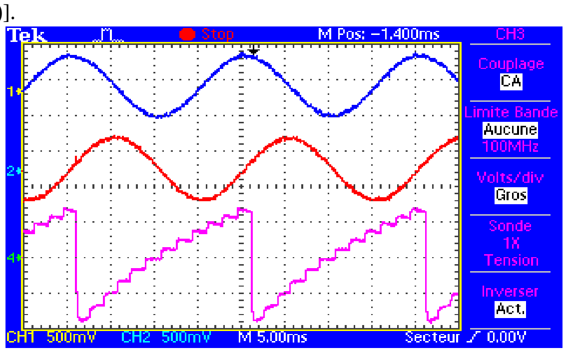

Fig 10. Experiment waveforms of the novel virtual line flux observer.

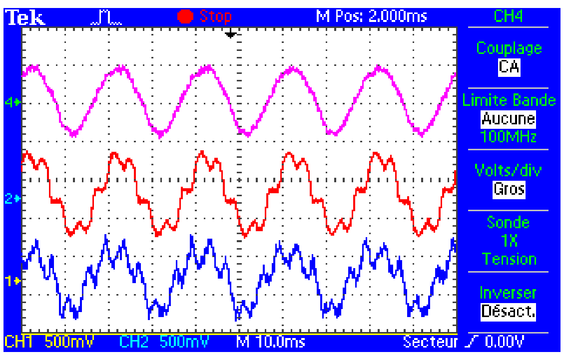

Fig 11. From top to bottom load ac current ac source current and active filter current.

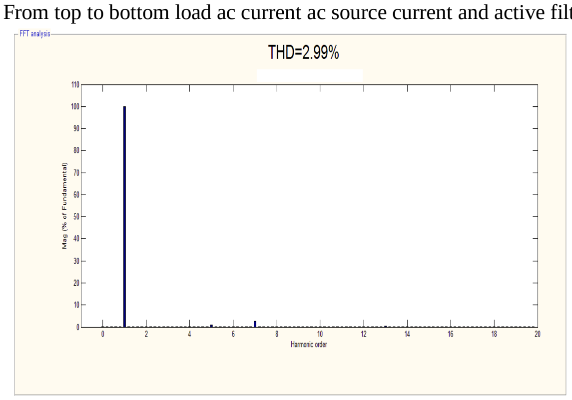

Fig 12. Ac source current harmonic spectrum versus frequency

Fig.7. Fig. 8. Fig 9. Presents the start up the PWM rectifier operation. It is noted the linear currents are sinusoidal and the control technique presents a very good dynamic behavior, Thais thanks to PI regulator behavior used control the DC-link voltage. Under APF operation, the line current becomes almost sinusoidal as well as in phase with line voltage, which gives near-to-unity power factor.

As Fig. 10 shows, the virtual line flux and oriented angles switch smoothly in the transient adjustment process, which indicates that the DPC control strategy of PWM rectifier has a fast dynamic performance and excellent output performance

4. CONCLUSION

This paper has proposed Direct Power Control (DPC) strategy based on a novel virtual flux observer with switching table to control PWM rectifier. The obtained results show that this control has a good dynamics, and it offers sinusoidal line currents (low THD) for ideal and distorted line voltage and compensates automatically the reactive power part to improve the main power factor to unity, the three-phase voltage-type PWM rectifier having also the function of an active power filter has been investigated and its effectiveness has been confirmed using a three-phase diode bridge rectifier with a smoothing reactor as a nonlinear load.

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